Batteries Included:

Top 10 Findings from Berkeley Lab Research on the Growth of Hybrid Power Plants in the United States

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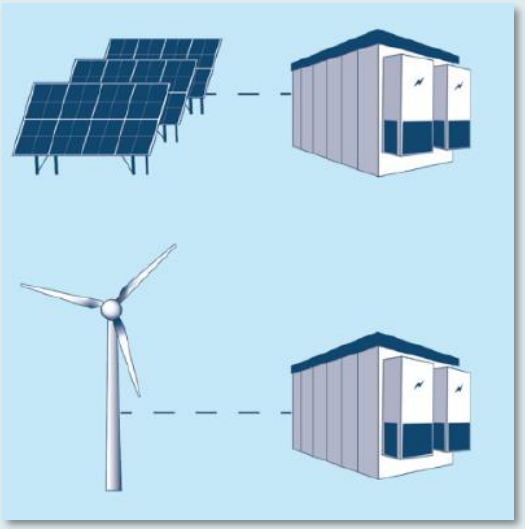
Presentation overview

- How we define hybrids
- Why this research matters
- Our top ten findings
- Summary and conclusions

Hybrid resources can encompass many different technologies and definitions

- "Hybrid" terminology sometimes applies to any project that combines multiple energy generation, storage, or load control technologies, whether physically or virtually linked



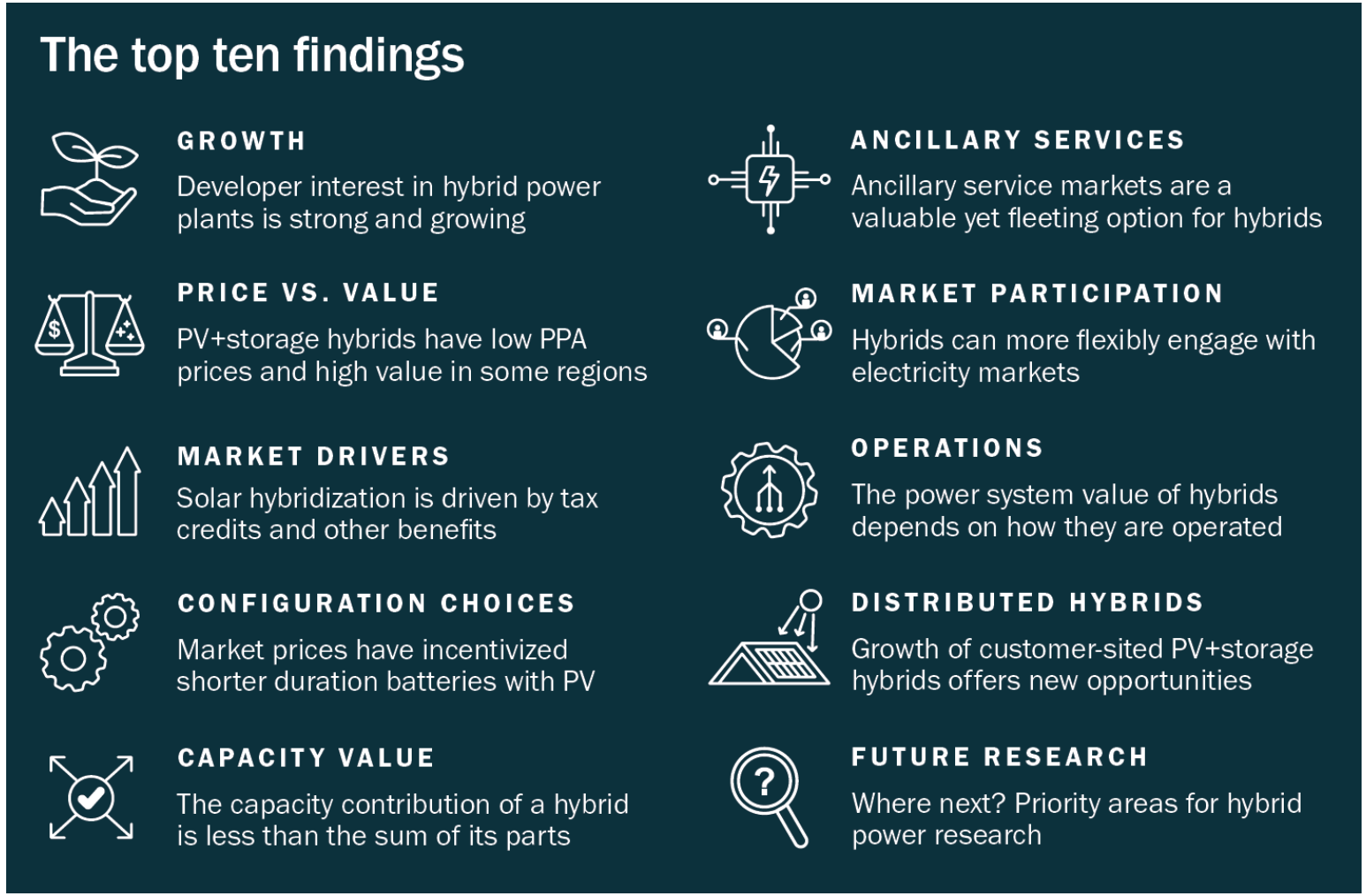
- We **define hybrid power plants** as:
  - Combinations of generation and storage
  - Operated either as a single or two separate units
  - Sited at the same location

- Our research has **not focused** on:
  - Solely combinations of generator types
  - Non-battery storage types
  - Virtual hybrid technologies

Why this research matters

- One of the most important electric power system trends of the 2010s was the **rapid deployment of standalone wind turbines and photovoltaic arrays**
- In the 2020s, **hybrids** and standalone storage are slated to become a **common form of deployment**
  - Growing needs for enhanced **flexibility** to balance variable renewable energy
  - Falling battery prices + cost synergies + tax credits involved with hybridization
- **Wholesale market rules** related to hybridization are **under development** within ISOs and at FERC
- Combining characteristics energy, storage, and conversion technologies poses complex questions for grid operations and economics.
  - **Need for information** on drivers, trends, costs/value, and challenges to deployment

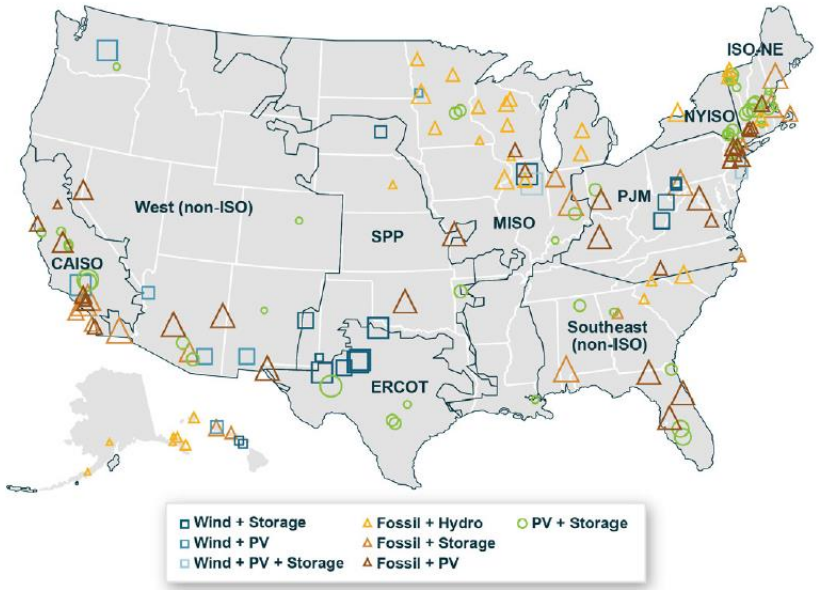
Package of complementary research performed over last 3 years at Berkeley Lab



1. Developer interest in hybrid power plants is strong and growing

- By end of 2021, there were more than **8 GW** of PV or wind hybrid plants online
  - Cumulative operational hybrid capacity **increased by 133%** from 2020 to 2021
  - Though there are a number of fossil+storage hybrid projects, they include a relatively low amount of storage compared with the size of the generation plant

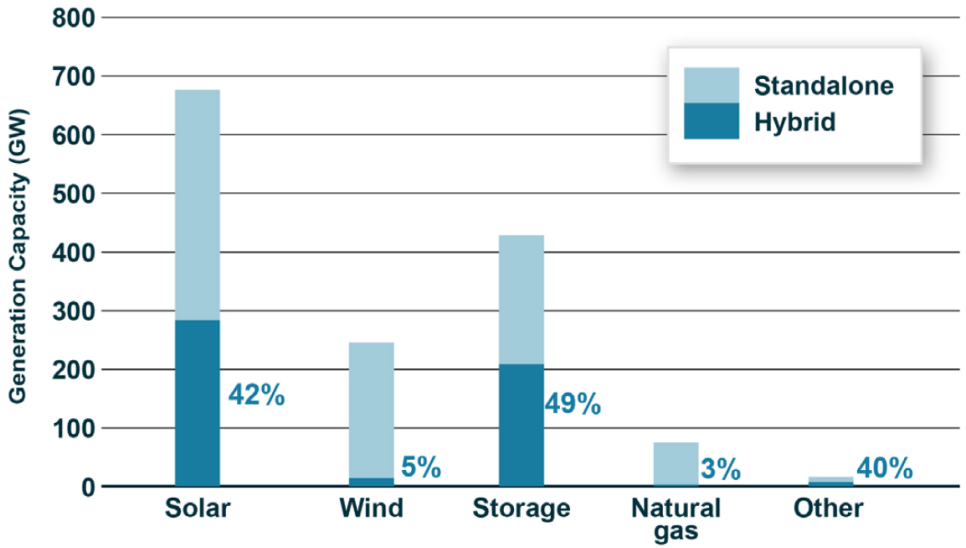
FIGURE 1. Location of Existing Hybrid Plants Through 2020



See our research on existing hybrid plants

- **Proposed plants** indicate growing interest in renewable hybrid configurations
  - More than **675 GW of solar** plants in the nation's **queues**;
  - **286 GW** (~42%) of this capacity was proposed as a **hybrid**

FIGURE 2. Capacity in Queues Through 2021

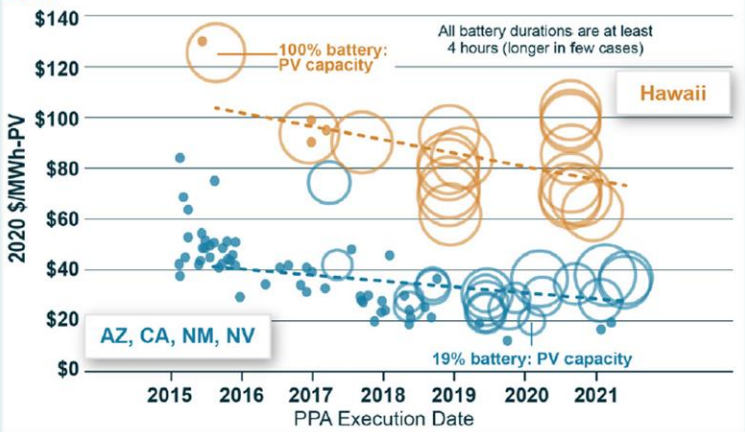


Many of these proposed plants will not ultimately reach commercial operations

See our research on proposed hybrid plants

2. PV+storage hybrids have low PPA prices and high value in some regions

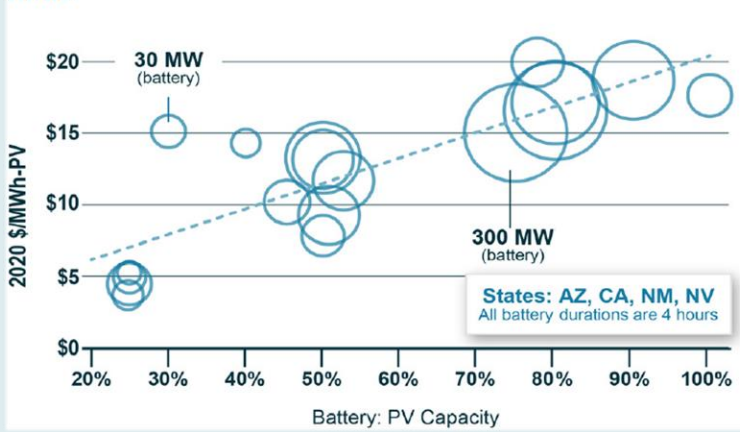
FIGURE 3. Levelized PV Hybrid PPA Prices by Execution Date



The price of PV hybrid plants is close to that of standalone PV and **falling**

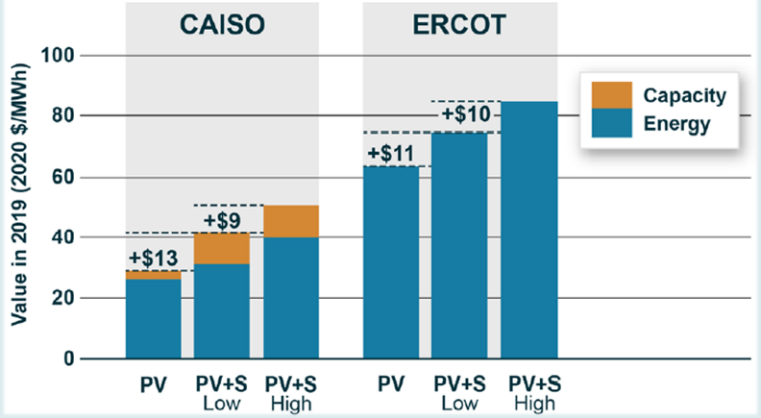
*In **Hawaii**, virtually all utility-scale PV plants with PPAs executed post-2017 include a battery*

FIGURE 4. Levelized Storage PPA Price Adder by Capacity Ratio



A hybrid's PPA price premium reflects the **size of its battery**

FIGURE 5. 2019 Market Value of Standalone PV and PV+storage Hybrids



The **net value** of hybridization appears to be positive

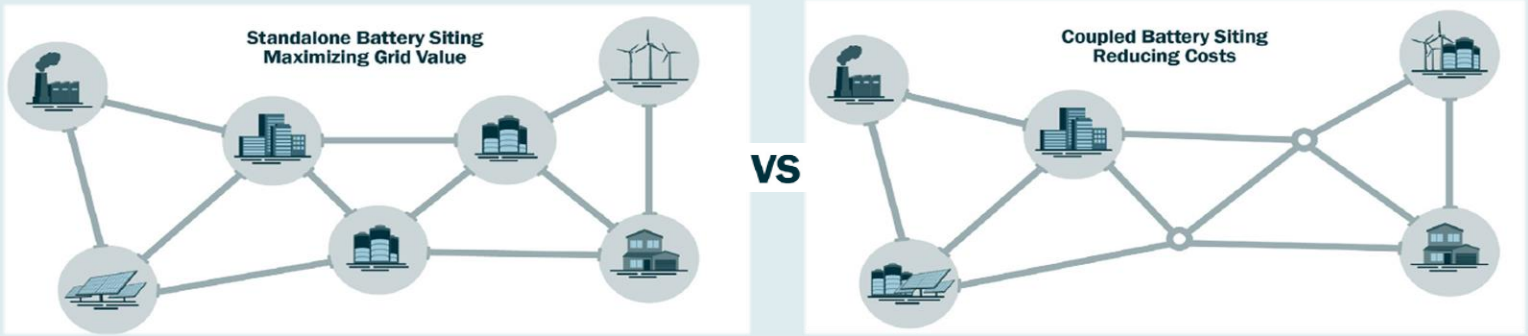
This result is stable even in a "low" value case which assumes simple dispatch based on day-ahead prices

See our research on hybrid PPAs

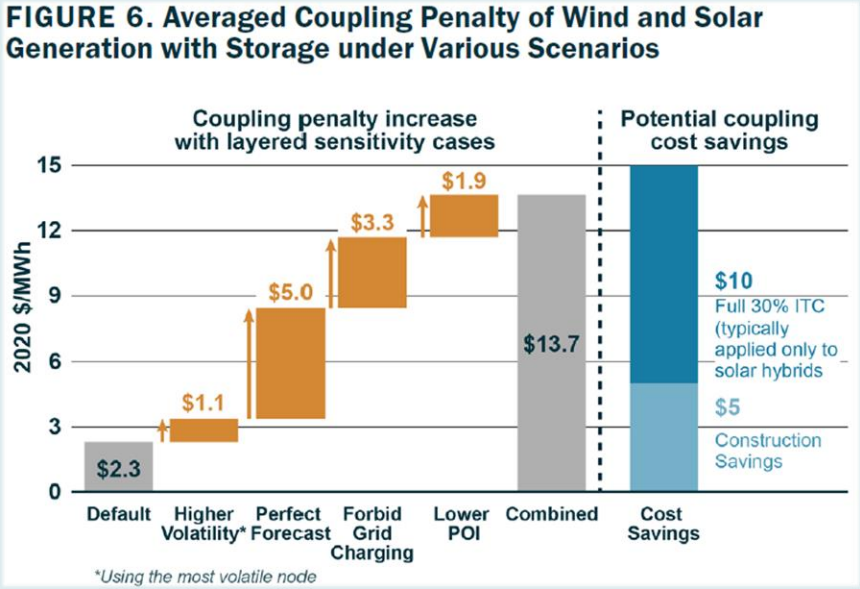
See our research on hybrid valuation

3. Solar hybridization is driven by tax credits and other benefits

- A renewable project's location might not be where storage provides the **most grid value**
- → we define delta as ***coupling penalty***



- Tax Credits are one, but not the only, reason for hybridization
  - **Share** equipment and interconnection/permitting **costs**
  - Capture clipped energy
  - Facilitate intraday **energy shifting**



Hybrid **coupling penalty** is largely **offset** by hybrid cost savings

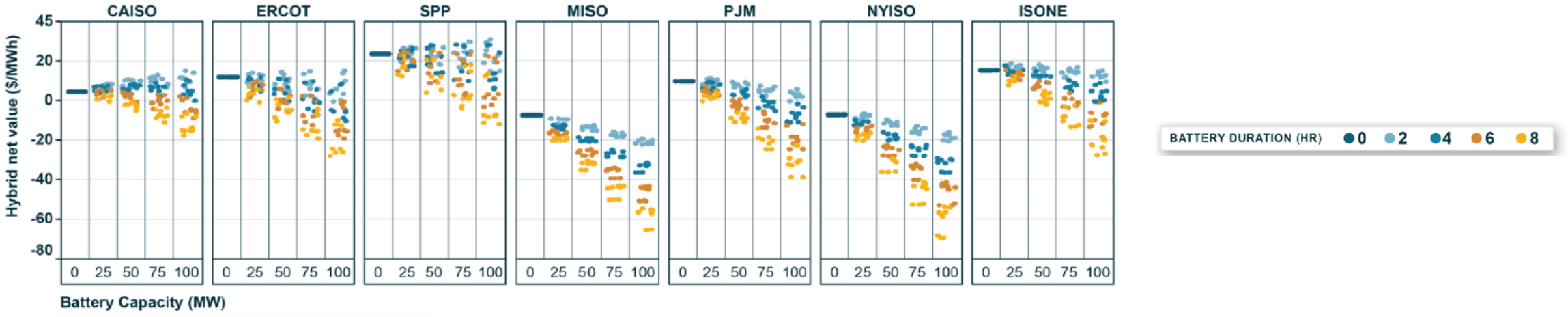
- Default grid value for independent siting (~$2.3/MWh) is substantially smaller than construction cost (~$5/MWh) and ITC (~$10/MWh) savings

See our qualitative and quantitative research on market drivers

4. Market prices have incentivized shorter duration batteries with PV

- Battery **duration and capacity** have the largest impact on hybrid net value
  - Inverter loading ratio and AC/DC coupling have secondary impacts

FIGURE 7. Impact of Battery Power Capacity (x-axis) and Duration (legend) on Solar Hybrid Net Value



- Storage durations of online and proposed projects are typically **1-4 hours**, aligning with our findings of higher net value for shorter duration batteries

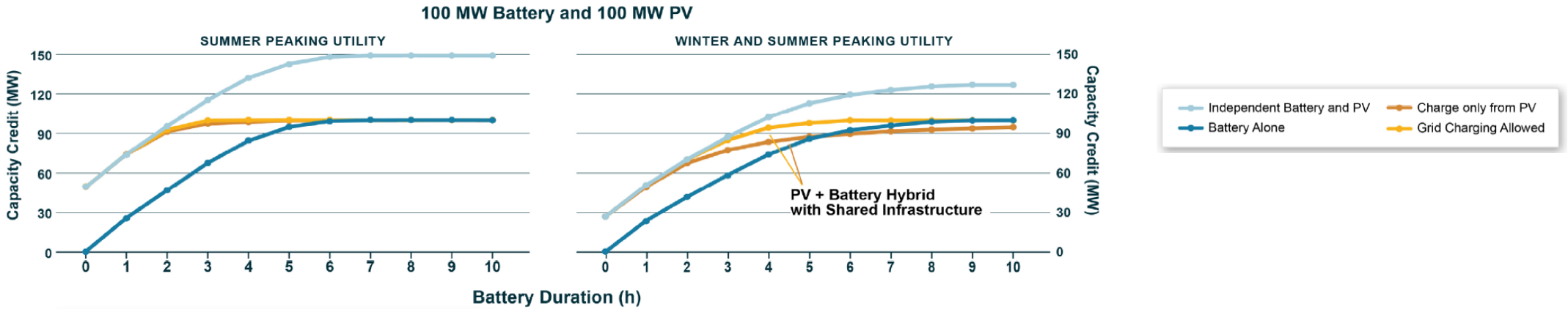
- Region-wide **solar contribution levels** drive solar hybrid value

See our research on hybrid configuration choices and value enhancement options

5. Capacity contribution of a hybrid is less than the sum of its parts

- Reliability accreditation to **support peak electricity demand** drives capacity value hybrids
- New methods are needed to **easily evaluate** the relative capacity contributions of hybrids consisting of several subsystems, across configurations, regions, and operational constraints
- **Shared infrastructure** (e.g. inverters / interconnection capacity) can limit the contribution of hybrid's constituent components

FIGURE 8. Capacity Credit Comparison between Battery, PV, and Hybrid Projects with Varying Storage Durations

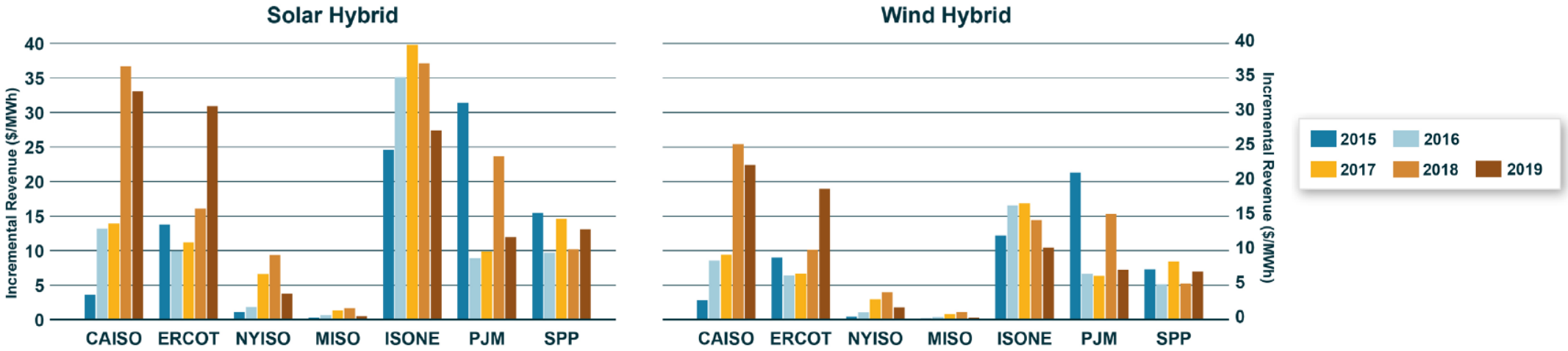


See our research on hybrid capacity contributions

6. Ancillary services are a valuable yet fleeting option for hybrids

- AS provision can provide **additional revenue** opportunities for hybrids depending on the region

FIGURE 9. Incremental AS Revenue ($/MWh) to Solar and Wind Hybrid Projects



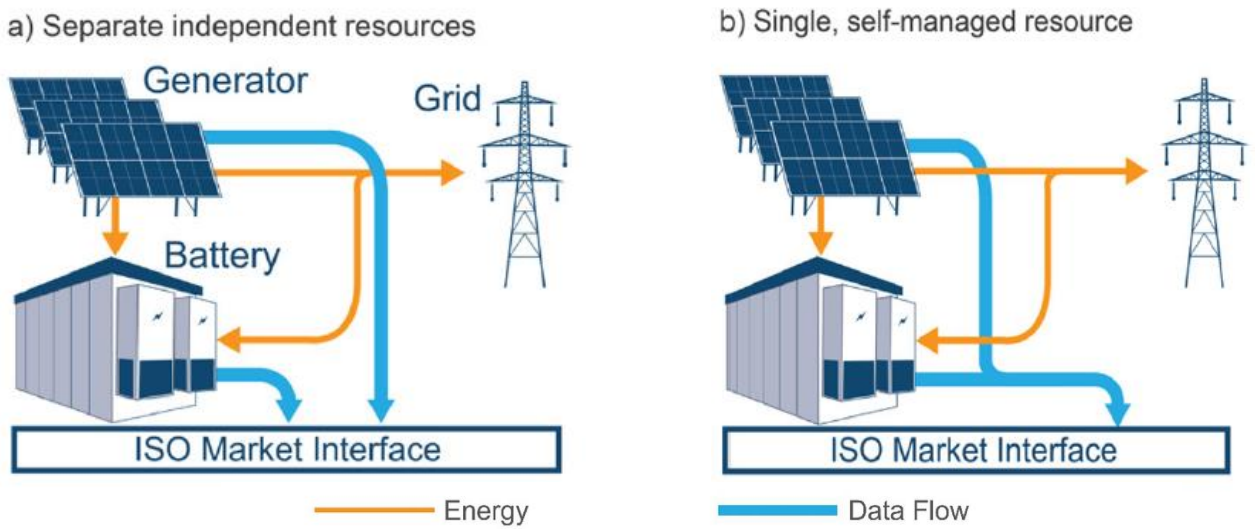
- Could provide system operators with access to lower-cost reliability services
  - Currently **limited opportunities** for standalone renewables to provide AS
  - ISO/RTOs could differentiate AS products to prioritize hybrid participation

- AS **markets are relatively small** compared to proposed batteries in queues

See our research on AS revenue opportunities

7. Hybrids can more flexibly engage with electricity markets

- Two high-level **market participation models** are being considered for hybrids:



- ISOs/RTOs continue to work on model details
  - Focus on **developing definitions and business practices** related to hybridization
  - Challenges include forecasting, market power mitigation, metering and telemetry

- Developer **preferences** between the two models are **mixed**

See our research on wholesale market participation options and hybrid business models

8. The power system value of hybrids depends on their operation

- Not all large-scale PV+storage hybrids are integrated into organized markets
  - Most operating hybrids in 2020 followed either (a) incentive program signals or (b) capacity & transmission demand charges instead of wholesale market price signals (c+d)

See our research on hybrid business models

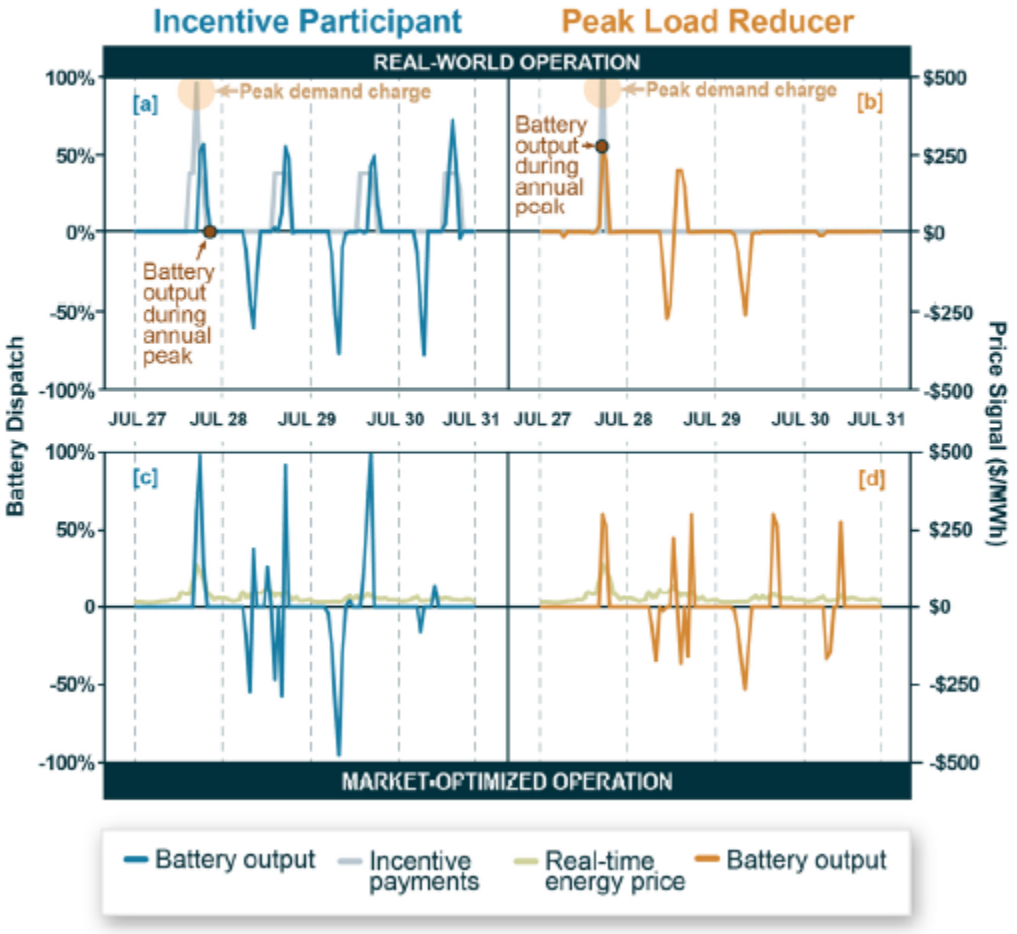
- Contractual requirements can **restrict the flexibility** of PV+storage hybrids, preventing optimal dispatch

See our research on hybrid PPAs

- Using behind-the-meter storage to maximize solar **self-consumption** (e.g. via net-billing tariffs) provides **little market value** for the electric system

See our research on customer-sited hybrid valuation

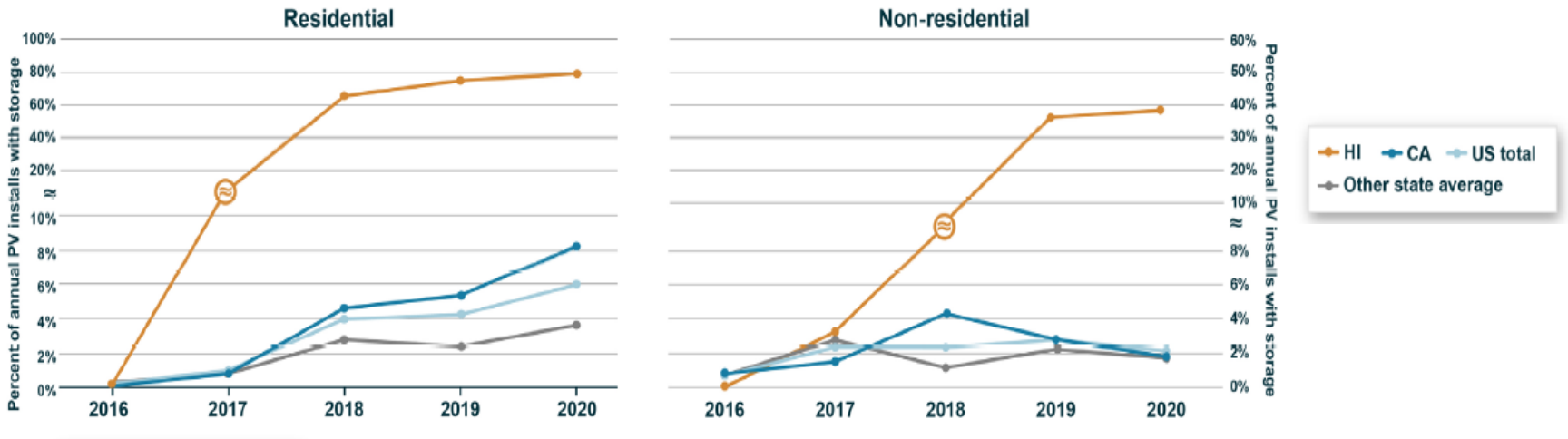
Figure 10. Empirical (top) vs. market optimized operation (bottom) and price signals for an incentive participant (left) and peak load reducer (right)



9. Growth of customer-sited PV+storage hybrids offers new opportunities

- Storage attachment rates are **rising for residential PV**, but less for non-residential BTM PV

Figure 11. Residential and non-residential storage attachment rate



- Batteries coupled to residential PV are becoming **larger**
- Residential PV installers have embraced storage more broadly than their non-residential counterparts
- **Pricing** for paired residential systems has been **trending up**
  - Might reflect current supply-chain constraints. Adding storage increases the installed price by about $1000/kWh of storage

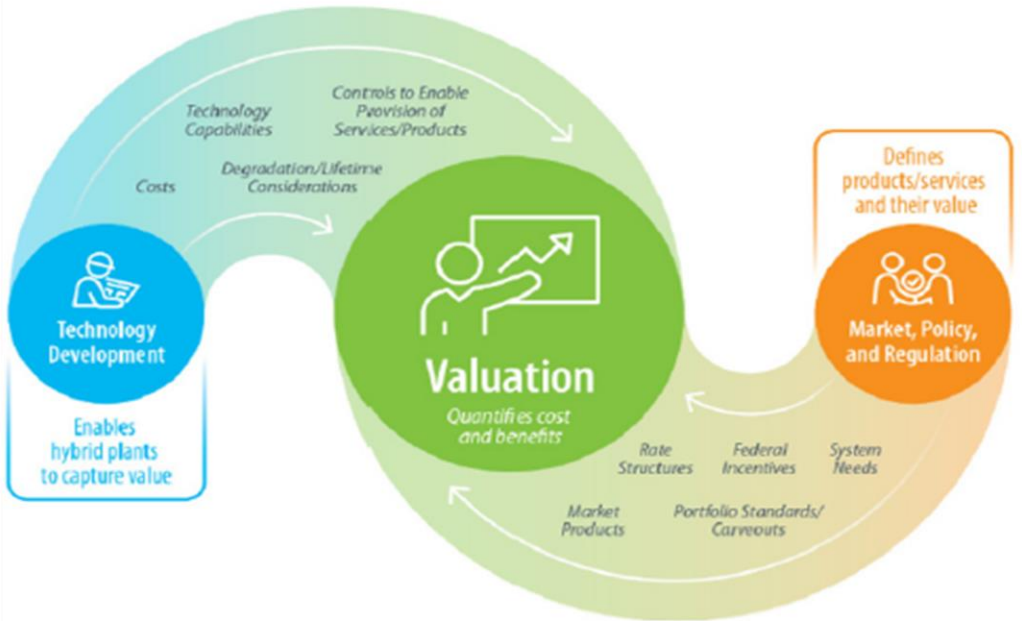
See our research on customer-sited hybrid market trends

10. Where next? Priority areas for hybrid power research

- More research is needed to understand the full capability of hybrid projects.
  - Project developers, system operators, planners, and regulators would benefit from better **data**, **methods**, and **tools** to estimate the costs, values, and system impacts of hybrid projects.

- Berkeley Lab's ongoing research focuses on
  - **Market, policy, and regulation topics**
  - **Valuation**

INFOGRAPH 3. Summary of Priority Areas for Research on Hybrids and their Mutual Dependencies



U.S. Department of Energy 2021

See the U.S. Department of Energy report

Summary

- Commercial interest in hybrid power plants continues to **grow rapidly**
  - Almost half of the 675 GW of solar in the queues is being proposed with batteries
  - **Key drivers** are cost synergies, enhanced operational flexibility, and tax credits
  - Net-value of hybrids is positive in a number of regions in the United States (i.e. **California, Southwest**)

- Market prices help explain key aspects of current market development trends
  - Region-wide **solar contribution** levels drive solar hybrid value
  - Market prices have incentivized **shorter duration** batteries

- Hybrids can **more flexibly** engage with electricity markets
  - **Ancillary service** markets are a valuable yet fleeting option for hybrids
  - Many large-scale hybrid operators focusing on **price signals not coming from wholesale markets**
  - Contractual requirements and tariff designs may **prevent optimal dispatch** of batteries

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For more information

Download the LBNL summary paper: https://emp.lbl.gov/publications/batteries-included-top-10-findings

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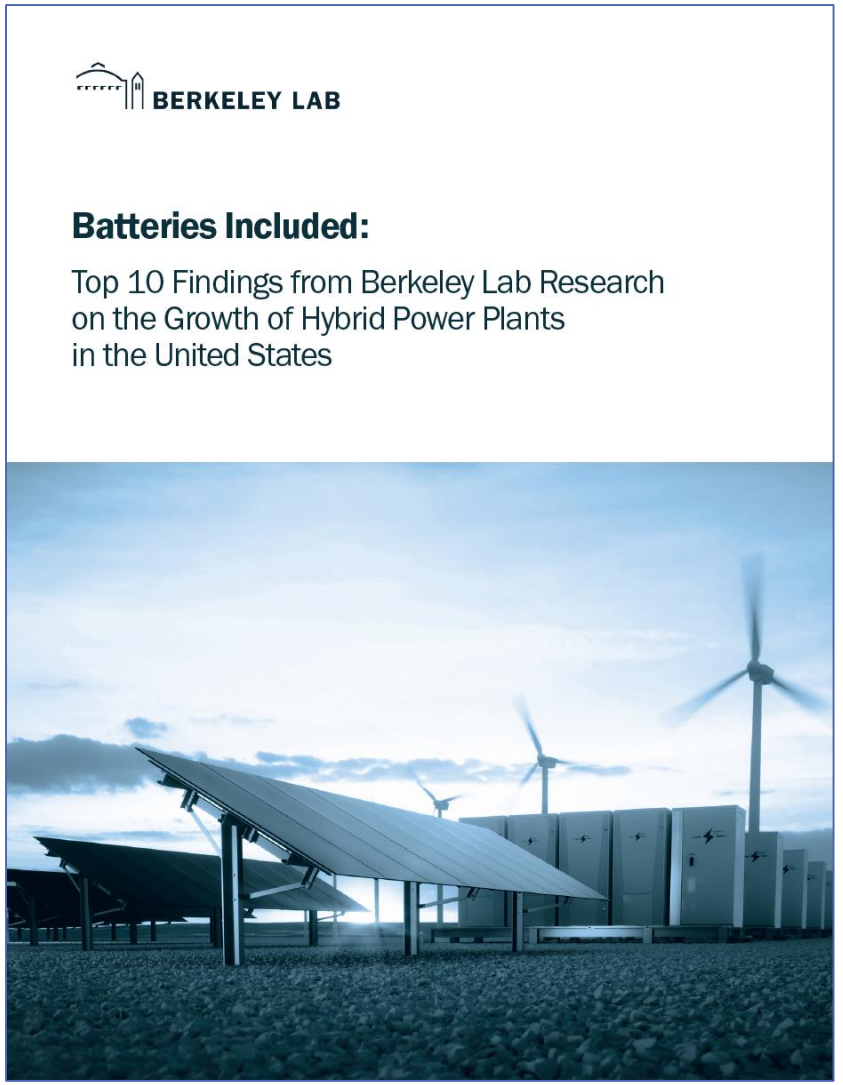

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